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Title Page

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Inside the 'Hurt Locker': The combined effects of explosive ordnance disposal and chemical protective clothing on physiological tolerance time in extreme environments

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ABSTRACT

Background: Explosive ordinance disposal (EOD) technicians are often required to wear specialised clothing combinations that not only protect against the risk of explosion but also potential chemical contamination. This heavy (>35kg) and encapsulating ensemble is likely to increase physiological strain by increasing metabolic heat production and impairing heat dissipation. This study investigated the physiological tolerance times of two different chemical protective undergarments, commonly worn with EOD personal protective clothing, in a range of simulated environmental extremes and work intensities

Methods: Seven males performed eighteen trials wearing two ensembles. The trials involved walking on a treadmill at 2.5, 4 and 5.5 km.h^{-1} at each of the following environmental conditions, 21, 30 and 37°C wet bulb globe temperature (WBGT). The trials were ceased if the participants' core temperature reached 39°C, if heart rate exceeded 90% of maximum, if walking time reached 60 minutes or due to volitional fatigue.

Results: Physiological tolerance times ranged from 8 to 60 min and the duration (mean difference: 2.78 min, $P>0.05$) were similar in both ensembles. A significant effect for environment (21>30>37°C WBGT, $P<0.05$) and work intensity (2.5>4>5.5 km.h^{-1}, $P< 0.05$) was observed in tolerance time. The majority of trials across both ensembles (101/126; 80.1%) were terminated due to participants achieving a heart rate equivalent to greater than 90% of their maximum.

Conclusions: Physiological tolerance times wearing these two chemical protective undergarments, worn underneath EOD personal protective clothing, were similar and predominantly limited by cardiovascular strain.

KEYWORDS: Core temperature; Personal protective equipment; Military; Heat Strain; Thermoregulation; Uncompensable heat stress

Introduction

Numerous occupations and sporting arenas necessitate that individuals perform arduous physical activity, while wearing personal protective equipment, under high ambient temperature. Explosive ordnance disposal (EOD) is one occupation that requires personal protective equipment to safeguard the technician from over pressure, fragmentation, impact and heat (Thake *et al*., 2009; Stewart *et al*., 2013; Stewart *et al*., 2014). Standard practice for an EOD technician involves periods of searching for a target, before undertaking activity in close proximity to the explosive device. These scenarios can differ in terms of their geographical location and in the intensity with which they are undertaken. Consequently, the EOD technicians wear specially engineered personal protective equipment which is extremely heavy (>30kg) and encapsulating (Stewart *et al*., 2013; Stewart *et al*., 2014). Unfortunately, the accumulative effects of the metabolic and environmental heat may create a condition of uncompensable heat stress, and predispose an individual to exertional heat illness (Frim and Morris, 1992; Stewart *et al*., 2011; Stewart *et al*., 2013; Stewart *et al*., 2014).

In an uncompensable heat stress scenario, the required evaporative capacity of the environment exceeds its maximum evaporative potential (Periard *et al*., 2012; Givoni and Goldman, 1972; Robinson *et al*., 1945). In this scenario a thermal steady state cannot be achieved in exercising humans as heat is continually stored within the body at a greater rate than is dissipated (Periard *et al*., 2012; Kraning and Gonzalez, 1991). It is well established that air exchange between the micro-environment beneath encapsulating personal protective equipment and the external environment has a significant impact on evaporative cooling and convective heat transfer (Gonzalez, 1988; Havenith *et al*., 2011; McLellan *et al*., 2013a; McLellan *et al*., 2013b). Although the role of military (Montain *et al*., 2004; Caldwell *et al*., 2011) and non-military (Armstrong *et al*., 2010; McCullough and Kenney, 2003) protective clothing in the development of heat strain has been examined extensively, few authors have considered the cardiovascular and thermoregulatory effects of wearing the heavy and cumbersome personal protective equipment required for EOD.

We have recently provided a comprehensive evaluation of the physiological tolerance times while wearing EOD personal protective equipment in isolation (Stewart *et al*., 2014). The findings indicated that participants experienced moderate-high levels of physiological strain, and that fatigue and work tolerance when wearing EOD personal protective equipment is based on cardiovascular rather than thermal strain regardless of the ambient environment (Stewart *et al*., 2014). Previous field investigations examining symptoms of heat strain in EOD technicians have also reported near maximal heart rates observed at the completion of the simulated work tasks (Stewart *et al.,* 2011; Stewart *et al*., 2013).

In some instances an EOD technician may also be required to don an additional layer of specialised clothing that repels the contact of chemical or biological agents. This is particularly pertinent if the target is located adjacent to a contaminated area or if the type or severity of threat is unknown. Although these items confer additional protection to the EOD technician, they further restrict body heat loss due to their high thermal resistance and low water vapour permeability (Caldwell *et al*., 2011). The additional air layers trapped within the protective ensemble further impairs heat loss (Cain and McLellan, 1998; Gonzalez, 1988) and exacerbates the uncompensable heat stress. In addition, respirators are commonly used in conjunction with chemical protective clothing to provide protection from air-borne hazards (McLellan *et al.*, 2013a). It is well established that there is increased resistance in inspiratory and expiratory breathing associated with the use of respirators (Butcher *et al*., 2006; Eves *et al*., 2005; Jetté *et al*., 1990). Consequently, the use of respirators in conjunction with protective clothing has been shown to decrease maximal oxygen uptake (Dreger *et al.*, 2006) and exercise tolerance (White and Hodous, 1987).

To our knowledge, no study has evaluated the physiological strain associated with chemical and EOD personal protective clothing. Therefore, the purpose of this study was to evaluate and compare the physiological tolerance times while wearing two different chemical protective undergarments, which are commonly worn with EOD personal protective clothing, in a range of simulated environmental extremes and work intensities.

Methods

Participants

Seven participants, recruited from the university community, volunteered for the study. All the volunteers provided their written informed consent to procedures approved by the University Human Research Ethics Committee and the study conformed to the current Declaration of Helsinki guidelines. To eliminate the confounding influences of gender on physiological responses to heat stress, only non-smoking males, free from any known cardiovascular, metabolic, and respiratory diseases were considered. The physical characteristics of the participants are as follows (mean ± SD): age = 25.5 ± 2 years, height = 1.81 ± 0.05 m, body mass = 77.4 ± 8.5 kg, body surface area 2.0 ± 0.1 m^2, sum of eight skinfolds 77.5 ± 23.7 mm, maximal oxygen uptake ($\dot{V}O_{2max}$) 58 ± 5 $ml.kg.min^{-1}$, heart rate max 190 ± 8 $beats.min^{-1}$. Participants were instructed to refrain from alcohol, tobacco, caffeine and strenuous exercise, and to consume 45 ml of water per kg of body mass in the 24 hours preceding each visit to the laboratory.

Preliminary measurements

Prior to undertaking the experimental trials of the study, height and nude body mass were recorded and body surface area was subsequently calculated (DuBois and DuBois, 1989). Skinfold thickness measures were obtained, using Harpenden (John Bull, West Sussex RH15 9LB, UK) callipers, on all participants at eight sites (biceps, triceps, subscapular, iliac crest, supraspinale, abdomen, front thigh and medial calf). $\dot{V}O_{2max}$ was determined by indirect calorimetry during a progressive incremental running protocol on a motorised treadmill (Hunt *et al*., 2012). Participants were also provided the opportunity to familiarise to both ensembles by walking around the laboratory and on the treadmill at the speeds to be utilised for the trials.

Experimental procedures

Participants were required to attend the laboratory on seven occasions, separated by a minimum of seven days. The first session involved the acquisition of $\dot{V}O_{2max}$, body composition and a familiarisation with the protective clothing and testing procedures.

During this visit the participants donned the protective clothing and walked a) around the laboratory and b) at each of the three work intensities (2.5, 4 and 5.5 km·h^{-1}) on the treadmill. The remaining six laboratory visits involved the participant walking on a treadmill, while wearing one of the ensembles, in an environmental chamber (4 x 3 x 2.5 m; length, width, height respectively). A Wet Bulb Globe Temperature (WBGT) of 21, 30 or 37°C was obtained by the following ambient temperatures and relative humidities: 24°C, 50%; 32°C, 60%; and 48°C, 20%; respectively. A simulated wind speed equivalent to ~4.5 km.h^{-1} and a radiant heat load (two 2400 Watts radiant heaters positioned ~1.3m above the participant) were incorporated throughout all of the trials. These environmental conditions were also monitored independently at the level of the participants' waist (Quest Temp, Airmet, Australia). Subjects were consider to be non-acclimatised to all environments (i.e. WBGT37) but resided in a subtropical location within Australia and that data collection occurred over the spring and summer months. During each of these laboratory visits the participant completed three treadmill-walking trials of 2.5, 4 and 5.5 km·h^{-1} with a 1% gradient. This equated to an external work rate (Pandolf *et al*., 1977) of ~139, 212 and 314 W.m^{-2} for a 77kg individual with a body surface area of 2 m^{-2}. The order of the testing, for both the speed and the environment, was balanced.

Personal protective equipment

During each trial participants wore either an Allen Vanguard (Explosive Protective Equipment, Newstead QLD 4006 Australia; 2.9kg) or a Saratoga™ Hammer Suit (Applied Response Solutions, Georgetown, TX, United States; 4.2kg) chemical protective undergarment and respirator (Promask with a pro2000 PF10 filter; Scott Safety, Lancashire, England). Due to the availability of the chemical undergarments all participants completed the Allen Vanguard ensemble before commencing the Saratoga. Both undergarments are air-permeable and charcoal impregnated, and comprised of a jacket, trousers, booties, gloves and hood. The same Med-Eng™ EOD9 suit (Allen Vanguard, Ogdensburg, New York, USA) consisting of a jacket, trousers, groin protection and a helmet (33.4kg) was donned during each trial over the chemical undergarments and respirator. As with the EOD ensemble the participants' base ensemble of a t-shirt, shorts, socks and underwear remained the same in all trials. Athletic shoes with a soft rubber sole were also worn during testing. These base ensemble requirements are standardised in accordance with American Society for Testing and Materials (F2688) (2011).

Measurements

Pre-trial hydration status was confirmed using urine specific gravity (USG, PAL 10s, ATAGO, Tokyo, Japan) of <1.020. If participants' did not meet the above guidelines they were given an additional 500 ml of room temperature water to be consumed prior to commencement of the trial. Following the consumption of the water the participant's core temperature was carefully monitored to ensure the gastrointestinal temperature did not change. Nude body mass was measured to the nearest 50 g (Tanita BWB-600, Wedderburn, Australia) and a cannula was inserted in the antecubital fossa. Venous blood samples were collected for the determination of serum osmolality as previously described (Taylor *et al*., 2012; Stewart *et al*., 2014).

Core and skin temperature were recorded at 30-s intervals throughout the trials. Core temperature was measured using an ingestible pill taken the evening prior to the experimental trials (CorTemp, HQ Inc, Palmetto, FL, USA) (Hunt and Stewart, 2008). Mean skin temperature (iButtons, eTemperature, OnSolution, Baulkham Hills, Australia) was calculated using an area-weighted mean of four sites (back of neck, inferior border of right scapula, dorsal right hand and proximal third of right tibia) (International Organisation for Standardisation, 2004). Mean body temperature was estimated using the formula developed by Stolwijk and Hardy (1966). Heart rate, recorded at 30-s intervals, was monitored throughout each trial using a heart rate monitor (Polar Team[2], Kempele, Finland) and chest strap. The physiological strain index (PSI) was calculated according to the equation proposed by Moran and colleagues (1998).

During each trial, standard termination criteria were applied in accordance with the ASTM (2011) guidelines: (1) core body temperature reaching 39.0°C; (2) 60 minutes of exercise; (3) heart rate >90% of maximum; or (4) self-withdrawal (e.g. fatigue or nausea). Following the attainment of one of the aforementioned termination criteria, the participant exited the environmental chamber into a thermoneutral air conditioned laboratory and the protective clothing was removed. Post-experimental nude body mass, following complete towel drying to remove surface sweat, and serum osmolality were recorded at the termination of each trial.

Following each trial participants rested in an air-conditioned laboratory. During this recovery period they were provided with food and fluid to a volume equivalent to 125% of the body mass loss in the preceding trial. This was undertaken to ensure recovery of body mass and hydration status prior to commencement of subsequent trials (Stewart *et al*., 2014). When core temperature (within 0.5°C) and heart rate (within 10 bpm) returned to baseline levels the participant provided a blood sample and had their nude body mass assessed. They participants then commenced donning the same fully dried protective clothing for the subsequent trial.

Statistical analysis

The primary outcome measure, tolerance time, was analysed using a three-way (suit * environment * work intensity) repeated measures analyses of variance (ANOVA). Serum osmolality, body mass loss and the final values recorded for core temperature, mean skin temperature, mean body temperature, heart rate and physiological strain at the termination of the trial were analysed using the same method. To determine if baseline physiological and hydration indices were similar, pre-trial heart rate, mean body temperature, serum osmolality and body mass were also analysed in a similar manner. Assumption of normal distribution of data was assessed using descriptive methods (skewness, outliers, and distribution plots) and inferential statistics (Shapiro–Wilk test). When the assumption of sphericity was violated, significance was adjusted using the Greenhouse-Geisser method. The effect of suit, environment and work intensity were tested. When the effect was significant, pair wise comparisons using a Bonferroni correction was used to investigate the differences. All statistical analyses were performed using SPSS (Statistical Package for the Social Sciences), version 19.0 (SPSS Inc, Chicago, IL) with the level of statistical significance set at $P < 0.05$. All values are expressed at means ± SD unless otherwise stated.

Results

Baseline data

Subjects commenced each of the trials from a resting physiological baseline, with no significant differences between trials (Table 1; all $P > 0.05$). Where multiple trials were performed on the same day the mean duration of rest was 81 ± 5 (range: 49–114) and 91 ± 7 (range: 57–172) mins in the Allen Vanguard and the Saratoga ensemble respectively.

insert Table 1 approximately here

Baseline physiological and hydration indices [mean ± SEM (standard error of the *mean*)].

Tolerance times

The seven participants completed all eighteen trials (total trials: 126) with no adverse events. Although the difference in tolerance time between the two ensembles approached statistical significance ($P = 0.051$) the differences were not physiologically relevant (Table 2 and Fig. 1; mean difference ± sem: 2.78 ± 1.14 min). Tolerance times ranged from 8 to 60 min and the termination criteria in both ensembles across the different environmental conditions and work rates were similar (Table 2). The maximum duration of exposure (i.e. 60 min) was achieved on only seven occasions (5.5%), five of these were in the Saratoga ensemble. All of these trials were conducted in the coolest environment, WBGT21, during the lowest work intensity, 2.5 $km \cdot h^{-1}$ (Table 2). The majority of trials across both suits (101/126; 80.1%) were terminated, and the participants withdrawn, after individuals achieved a heart rate equivalent to greater than 90% of their maximum. A total of twelve trials (9.5%) were terminated after participant's core temperature exceeded 39°C and six trials were stopped due to volitional fatigue/nausea (4.7%).

A significant effect for environment ($P<0.001$) and work intensity ($P < 0.001$) was observed in tolerance time (Table 2 and Fig. 1). Tolerance times were significantly greater ($P < 0.05$) in the WBGT21 compared to WBGT30 and WBGT37 environments. Tolerance times were also longer in the WBGT30 compared to the WBGT37 conditions. A similar trend was evident for work intensity with the lower work intensities lasting for longer than the higher intensities (2.5 > 4 > 5.5 $km \cdot h^{-1}$; $P < 0.05$).

insert Table 2 approximately here

Table 2. Tolerance time [mean ± SD (range)] and termination criteria for each participant in both ensembles across the different environmental conditions and work rates.

insert Figure 1 approximately here

Figure 1. Tolerance time (mean ± SD) in both ensembles across the different environmental conditions and work rates.

Physiological data at the cessation of the trials

At the cessation of the experimental trials no significant differences between the ensembles (Table 3) were observed in core temperature (P=0.298), heart rate (P=0.236), skin temperature (P=0.447), mean body temperature (P=0.273), PSI

(P=0.995), or blood osmolality (P=0.738). A significant difference was observed in percent body mass loss (P=0.001); with participants losing more in the Saratoga trials (mean difference ± sem: 0.18 ± 0.03%).

Significant main effects were observed between the three work intensities in core temperature, heart rate, skin temperature, mean body temperature, PSI and body mass loss (all P<0.01; Table 3). Post hoc analysis showed that core temperature, skin temperature, mean body temperature, body mass loss and PSI were lower (P<0.05) in the highest intensity compared to 2.5 and 4 $km{\cdot}h^{-1}$. Body mass loss was also lower (P<0.05) in the 5.5 $km{\cdot}h^{-1}$ compared to the 4 $km{\cdot}h^{-1}$ trials. No post hoc differences (P>0.05) were observed in heart rate. The environmental conditions only had an effect on skin temperature (P<0.001) and body mass loss (P=0.003). Skin temperature was significantly higher (P<0.05) in the WBGT30 and the WBGT37 trials compared to the WBGT21 trials. The body mass lost at the end of the WBGT37 trials was lower (P<0.05) than the WBGT21 and WBGT30 trials.

insert Table 3 approximately here

Table 3. Physiological and hydration indices (mean ± SD) at the cessation of the trials in both ensembles across the different environmental conditions and work rates.

Discussion

This is the first study to systematically compare the physiological tolerance times of two air-permeable, charcoal impregnated chemical protective undergarments while worn in combination with EOD personal protective clothing. The main findings of the present study demonstrates that although the difference in tolerance time between the two ensembles approached statistical significance, the differences were not physiologically relevant and there were no differences between the ensembles in terms of cardiovascular or thermoregulatory strain. Further, the physiological effects of wearing the two ensembles were similar as demonstrated by the analogous termination criteria at each condition and the similar body temperature, heart rate and body mass loss observed at termination. In addition, we were able to confirm that tolerance time is primarily determined by cardiovascular rather than thermoregulatory strain.

Emergency first responders, such as firefighters, the police and military, are often required to wear personal protective clothing when attending to emergency calls (Taylor *et al*., 2012). The increased metabolic demand that occurs when wearing additional protective clothing is well established, and has been recognised for many years (Caldwell *et al*., 2011; Dorman and Havenith, 2009; Nunneley, 1989; Taylor *et al*., 2012). Our findings suggest that physiological tolerance times were similar (mean difference 2.78min; Figure 1 and Table 2) when wearing two commonly employed chemical undergarments in addition to an EOD ensemble across a range of simulated environments and workloads. The current data also suggest that the physiological effects of wearing the different undergarments were similar as the termination criteria (Table 3), and the thermoregulatory and cardiovascular outcomes measures were comparable at termination (Table 2). Unsurprisingly, our data also suggest that EOD personnel should be cognisant that tolerance times are significantly reduced in warmer ambient environments and when work intensities are increased. A greater percentage of trials were terminated (80% *c.f.* 69%) due to excessive heart rates, when the chemical undergarments were added to the EOD suit, in comparison to the EOD ensemble in isolation (Stewart *et al*., 2014). Moreover, in comparison to wearing chemical garments alone (McLellan *et al.*, 3013a; McLellan *et al.*, 3013b; Dorman and Havenith, 2009; Havenith *et al.,* 2011) the current ensembles create a significantly higher metabolic burden and physiological tolerance is subsequently reduced. These findings have practical implications for implementing work-rest cycles; when performing tasks requiring a high metabolic demand and/or working in warm environments when wearing these EOD and chemical ensembles.

When working under greater thermal and physical loads, physical exhaustion can occur at much lower core temperatures (Caldwell *et al*., 2011). The termination criteria in both ensembles were similar (Table 2) and support the hypothesis that cardiovascular, rather than thermal strain, limits work tolerance under certain heat-stress conditions while wearing encapsulated protective clothing (McLellan *et al*., 2013a; Stewart *et al*., 2014). Over 80% of the trials were terminated in the current study as a result of participants' heart rate exceeding 90% of their maximum, in accordance with the ASTM (2011) guidelines. In fact, all of the trials were ceased based on the heart rate termination criteria in the highest work intensity (5.5 $km.h^{-1}$)

across the three environments. It is likely that the metabolic cost of the walking with this heavy and encapsulating ensemble, equivalent to approximately 50% of the participants' body weight, and the bodies attempt to maintain thermal homeostasis by increasing heart rate, skin temperature and sweat rate contributed to this increase in cardiovascular strain (Beekley *et al.*, 2007). This is particularly evident in the higher workloads (4 and 5.5 km.h^{-1}) as only 4 of the 84 trials completed at these intensities were terminated based on excessive core temperatures. Further, as all of the trials in the highest work intensity, regardless of the ambient environment, were terminated after a very short duration (18.1 min on average) due to excessive cardiovascular strain; body temperature, heart rate and body mass loss was typically lower in comparison to the other work intensities.

As previously described, EOD personnel are often required to wear additional clothing that repels the contact of chemical or biological agents from contact with the skin. Although we have previously evaluated the physiological tolerance times while wearing EOD personal protective clothing in isolation (Stewart *et al*., 2011; Stewart *et al*., 2014), there is no data examining the effects of adding a chemical protective undergarment and respirator to this ensemble. Despite finding no significant differences between these chemical undergarments, the tolerance times wearing these ensembles were reduced in comparison to the EOD alone (Stewart *et al*., 2014). Using the same methodological design and participants with similar demographics (all male, ~25 years, $\dot{V}O_{2max}$ ~57 ml.kg.min^{-1}, mass ~78kg and height ~180cm in both studies) tolerance times were on average 4.1 and 6.9 min less with the addition of the Saratoga and the Allen Vanguard undergarments to the EOD ensemble (Stewart *et al*., 2014). This is interesting considering the addition of the undergarments and respirator added only 9-12% to the total weight of the EOD ensemble and equated to differences of 12-20% in tolerance time. Moreover, physiological strain appears greater, on average, in these ensembles compared to the EOD alone (Stewart *et al*., 2014).

When multiple layers of protective clothing are worn successive trapped air layers are formed (McLellan *et al.*, 2013a). Each of these layers of trapped air creates its own microenvironment through which heat transfer must occur before being dissipated to the external ambient environment (McLellan *et al.*, 2013a; Sullivan and

Mekjavic, 1992). As these pockets do not naturally exchange air with the environment, thermoregulation is further impaired (McLellan *et al.*, 2013a). Therefore, it is likely that the extra microenvironment and the addition of the respirator, not the extra mass of the extra layer of chemical protective clothing, contributed to the reduced tolerance times compared with the EOD ensemble in isolation. However, alterations in moisture vapour permeability and changes in weight distribution following the addition of the chemical garments may also be partially responsible for the decreased tolerance times.

One limitation of the present study that should be acknowledged is the order of testing. Although the environments and work intensities were randomised for all trials, due to methodological constraints and the availability of garments, all subjects completed the Allen Vanguard trials prior to the Saratoga trials. Furthermore, the current findings are limited to a small sample of young males with a relatively high aerobic fitness. For practicality reasons core temperature was assessed in the current study using the gastrointestinal pill. It is well established that this method demonstrates a delay relative to oesophageal temperature, but not rectal temperature which it generally exceeds, when body temperatures change rapidly (Teunissenetal *et al.,* 2012; Taylor *et al.,* 2014). Consequently, core temperature, mean body temperature and PSI may all be higher than those reported in the current study if a different technique (e.g. oesophageal temperature) was employed to assess core temperature. Finally, repeated bouts of activity on the same day is typical of what occurs in the field; however the recovery times employed in the current study are significantly greater than that which is feasible in an emergency situation. Future research is therefore warranted to examine the effects of repeated bouts of activity on the development of uncompensable heat stress and strategies to mitigate heat stress in these ensembles.

In summary, this study indicates that physiological tolerance times are similar in two chemical protective undergarments commonly worn underneath EOD personal protective clothing across a range of simulated environments and work intensities. This study also found that physiological tolerance times are significantly reduced in higher ambient environments and work intensities. Moreover, work tolerance is limited by cardiovascular strain, as demonstrated by near maximal heart rate, rather than thermal strain.

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Conflict of interest

The authors declare no conflict of interest.

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Table 1. Baseline physiological and hydration indices [mean ± SEM (standard error of the *mean*)].

Table 2. Tolerance time [mean ± SD (range)] and termination criteria for each participant in both ensembles across the different environmental conditions and work rates.

Table 3. Physiological and hydration indices (mean ± SD) at the cessation of the trials in both ensembles across the different environmental conditions and work rates.

Figure 1. Tolerance time (mean ± SD) in both ensembles across the different environmental conditions and work rates.

Speed ($km \cdot h^{-1}$)	**Ensemble**	**HR (bpm)**	**T_{mb} (°C)**	**Serum Osmolality (mOsmol/kg)**	**Body Mass (kg)**
2.5	Allen Vanguard	95±2.3	36.5±0.1	291±1	77.5±2.9
	Saratoga	88±2.7	36.6±0.1	291±2	77.7±2.8
4	Allen Vanguard	100±3.5	36.5±0.1	293±1	77.6±2.8
	Saratoga	94±2.9	36.6±0.0	294±1	77.9±2.9
5.5	Allen Vanguard	101±4.2	36.5±0.1	294±1	77.6±2.9
	Saratoga	92±2.9	36.5±0.1	293±1	77.7±2.9

HR, heart rate; bpm, beats per minute; T_{mb}, mean body temperature.

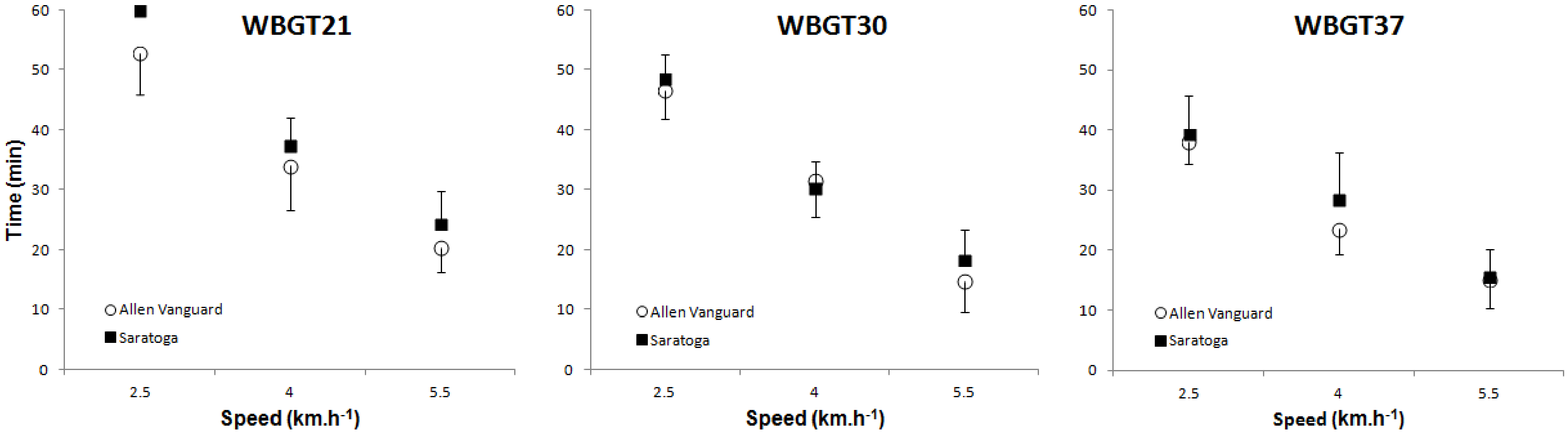
WBGT (°C)	Speed ($km \cdot h^{-1}$)	Tolerance Time (min)		HR (> 90% max)		Tc (> 39°C)		Self-withdrawal		Duration (= 60mins)	
		AV	ST	AV	ST	AV	ST	AV	ST	AV	ST

	2.5	52.8±6.9 (40.5-60.0)	59.8±0.6 (58.8-60.0)	4	1		1	1		2	5
21	**4**	34.0±7.5 (26.0-43.5)	37.2±4.8 (32.0-44.5)	7	7						
	5.5	20.4±4.1 (14.0-24.5)	24.2±5.5 (17.0-31.5)	7	7						
	2.5	46.5±4.6 (41.0-53.0)	48.4±4.2 (42.5-53.0)	3	3	2	3	2	1		
30	**4**	31.5±6.0 (25.0-40.5)	30.4±4.4 (25.0-39.0)	6	6	1	1				
	5.5	14.7±5.1 (9.0-21.5)	18.2±5 (14.0-26.5)	7	7						
	2.5	38.1±3.8 (33.5-42.5)	39.4±6.3 (31.0-46.5)	5	5	1	1	1	1		
37	**4**	23.6±4.2 (16.0-29.0)	28.6±7.8 (18.5-43.5)	6	6	1	1				
	5.5	15.3±5 (10.0-21.5)	15.7±4.5 (8.0-21.5)	7	7						

AV, Allen Vanguard; ST, Saratoga; WBGT, wet bulb globe temperature; HR, heart rate; Tc, core temperature.

	Core Temperature (°C)		Heart Rate (bpm)		Skin Temperature (°C)		Whole Body Temperature (°C)		Physiological Strain Index		Serum Osmolality (mOsmol/kg)		Body Mass Loss (%)	
WGBT21	AV	ST	AV	ST	AV	ST	AV	ST	AV	ST	AV	ST	AV	ST
2.5 km.hr^{-1}	38.3±0.5	38.4±0.7	157.5±15.4	156.4±14.6	37.3±0.4	37.3±0.5	38.0±0.5	38.4±0.4	6.0±1.6	6.8±1.2	297±4	295±3	1.3±0.1	1.7±0.5
4 km.hr^{-1}	38.3±0.4	38.5±0.4	171.0±6.7	171.9±7.9	37.4±0.2	37.4±0.4	38.1±0.3	38.4±0.3	7.1±0.7	7.4±0.7	295±3	297±4	1.1±0.5	1.4±0.2
5.5 km.hr^{-1}	38.0±0.3	38.2±0.4	169.7±6.4	174.0±8.2	37.3±0.3	37.3±0.4	37.8±0.3	38.1±0.3	6.3±0.8	6.5±0.9	296±3	297±7	1.0±1.1	0.9±0.3
WBGT30														
2.5 km.hr^{-1}	38.5±0.4	38.6±0.5	160.2±18.3	160.9±17.8	38.3±0.4	38.0±0.4	38.6±0.4	38.6±0.4	7.3±1.2	7.3±0.9	295±4	298±5	1.4±0.3	1.7±0.6
4 km.hr^{-1}	38.3±0.4	38.3±0.3	170.6±8.3	172.9±7.8	38.3±0.4	37.8±0.5	38.3±0.4	38.2±0.4	7.1±1.2	6.7±0.8	295±6	297±3	1.3±0.6	1.3±0.4
5.5 km.hr^{-1}	37.8±0.3	38.0±0.5	172.3±7.9	172.6±7.6	37.7±0.6	37.5±0.3	37.8±0.2	37.8±0.4	6.0±0.8	6.1±0.8	295±4	297±4	0.7±0.4	0.8±0.2
WGBT37														
2.5 km.hr^{-1}	38.3±0.5	38.6±0.4	166.0±14.1	165.0±16.9	38.5±0.3	38.5±0.3	38.4±0.4	38.5±0.3	7.1±1.1	6.7±0.4	297±3	297±6	1.2±0.2	1.6±1.0
4 km.hr^{-1}	38.0±0.5	38.5±0.5	171.4±9.5	172.9±7.6	38.2±0.3	38.5±0.4	38.2±0.4	38.5±0.5	6.8±1.1	7.1±1.3	297±6	297±6	0.9±0.4	1.2±0.5
5.5 km.hr^{-1}	37.7±0.5	37.9±0.3	172.6±7.4	172.7±8.3	37.9±0.7	37.9±0.8	37.9±0.4	37.8±0.3	6.2±1.0	5.4±0.6	298±3	295±5	0.6±0.2	0.5±0.2
Summary of Within / Between Effects														
Suit:	P=0.298		P=0.236		P=0.447		P=0.273		P=0.995		P=0.738		P=0.001	
Environment:	P=0.541		P=0.170		P<0.001		P=0.250		P=0.732		P=0.701		P=0.005	
Speed:	P=0.001		P=0.004		P=0.003		P<0.001		P=0.009		P=0.936		P<0.001	

AV, Allen Vanguard; ST, Saratoga; WBGT, wet bulb globe temperature; bpm, beats per minute.


WBGT21
WBGT30
WBGT37
Time (min)
Speed (km.h-1)
Allen Vanguard
Saratoga
0
10
20
30
40
50
60
2.5
4
5.5